Ferrofluid™ Damped ED Receivers

Introduction

A new damping technique has been developed that provides adjustable damping without a screen. Ferrofluid injected into the magnetic gap of the receiver's motor acts as a viscous damper to reduce the motion of the armature at resonance (Figure 1). The fluid is a suspension of microscopic magnetic particles (Fe_3O_4) in viscous oil that is retained by the magnetic field in the receiver's motor.

Fluid-damped Response

The amount of damping can be adjusted over a wide range by selecting the appropriate fluid volume. Figure 2 on the next page shows that the range of damping options extends from as little as 2dB up to critically damped (i.e., delta peak ± 0.5dB relative to 1 kHz). The peaks in the response are reduced without affecting the nominal sensitivity at 500Hz. Figure 3 (next page) shows the same receivers under constant current drive conditions.

"Damping" refers to the change in the mechanical resonance, which is the first peak in the frequency response with shorter ITE tubing (i.e., the peak between 2kHz and 3kHz voltage drive for the ED receiver).

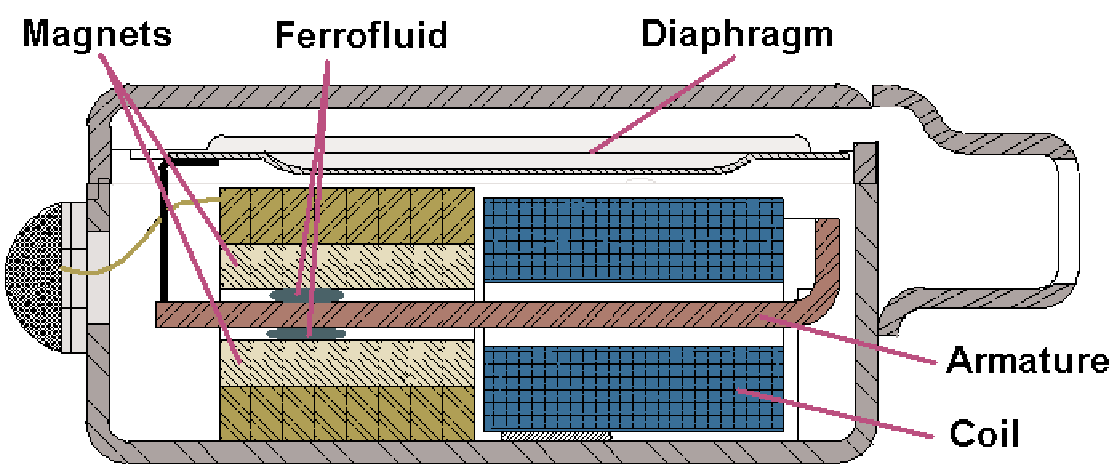

Figure 1: Cross-section of the Knowles FED receiver (i.e., ferrofluid-damped ED receiver)

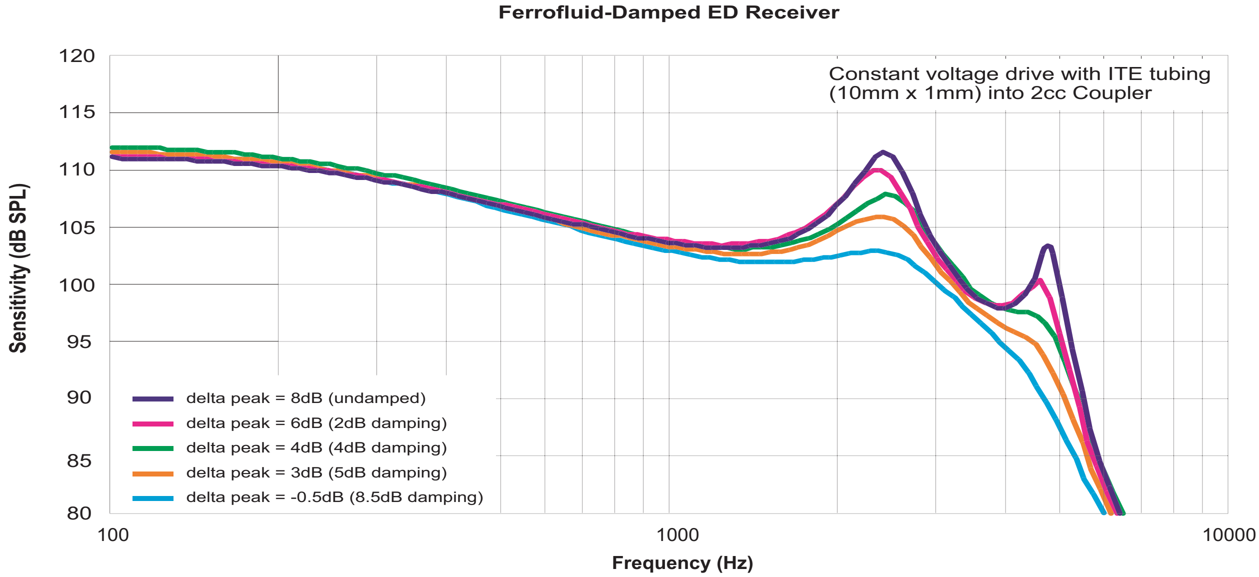

Figure 2: Frequency response curves under constant voltage drive conditions for fluid-damped FED receivers and a response curve for an undamped ED receiver. Labels in legend are the delta peak values.

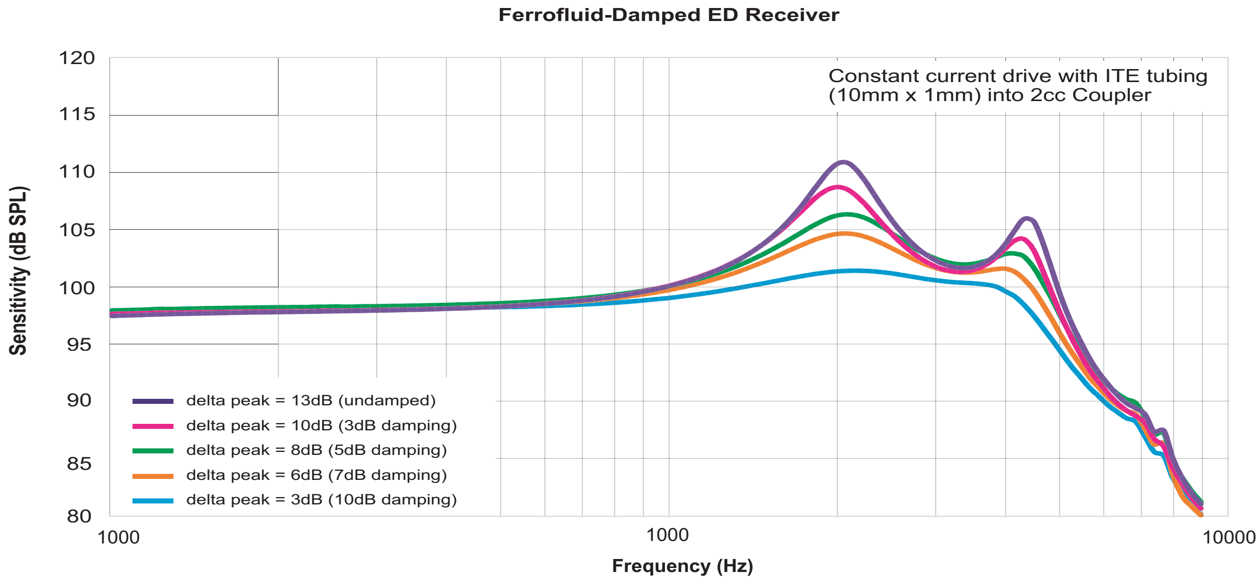

Figure 3: Frequency response curves under constant current drive conditions for fluid-damped FED receivers and a response curve for an undamped ED receiver. Labels in legend are the delta peak values.

Damping is calculated by subtracting the damped delta peak from the undamped delta peak and is specified as “dB damping relative to X”, where X = 8dB constant voltage drive for the ED receivers (see Equations 1 and 2).

$$\text{Delta Peak} = \text{Peak Sensitivity (dB SPL)} - \text{Sensitivity (dB SPL)} \ @ \ 1\text{kHz} \tag{1}$$

$$\text{dB Damping} = \text{Delta Peak}_{undamped} - \text{Delta Peak}_{damped} \tag{2}$$

Knowles specifies fluid damping under test conditions that include ITE or BTE tubing connected to a 2cm³ coupler and constant voltage drive. The amount of damping will be similar under different acoustic loads (i.e., various tubing lengths and 2cm³ or Zwislocki-type couplers). Ferrofluid can dramatically reduce the mechanical resonance and the tubing resonances above the mechanical peak (i.e., > 2kHz). The amount of peak damping is shown in Figure 4 below for the FED receiver connected to ITE tubing. The second peak (tubing resonance) falls off much faster than the mechanical peak. However, when using longer tubing (i.e., BTE tubing), the fluid is not as effective in damping the tubing resonance below the mechanical peak (i.e., peak at ~1.3kHz).

Damping Options

The choice of damping method depends on the application. Until recently there were three damping options available: Type I (screen), Type II (screen + modified barometric relief), and Type III (modified barometric relief). For ITE and CIC applications, eliminating a screen in the port tube is desired because of potential problems due to wax build-up. Ferrofluid can be substituted for screen damping. Figure 5, on the next page, shows a magnified view of the peaks for several types of damping when ITE tubing is used.

For BTE applications, the multiple resonant peaks created by the longer tubing are affected to different degrees by a screen (Type I), a diaphragm pierce (Type III), and ferrofluid. Ferrofluid alone is not as effective as Type II in reducing the first (acoustic) peak in the BTE response curve (i.e., peak near 1.3kHz). A combination of fluid damping and Type III damping is recommended to decrease all of the peaks when long tubing is used (Figure 6, next page).

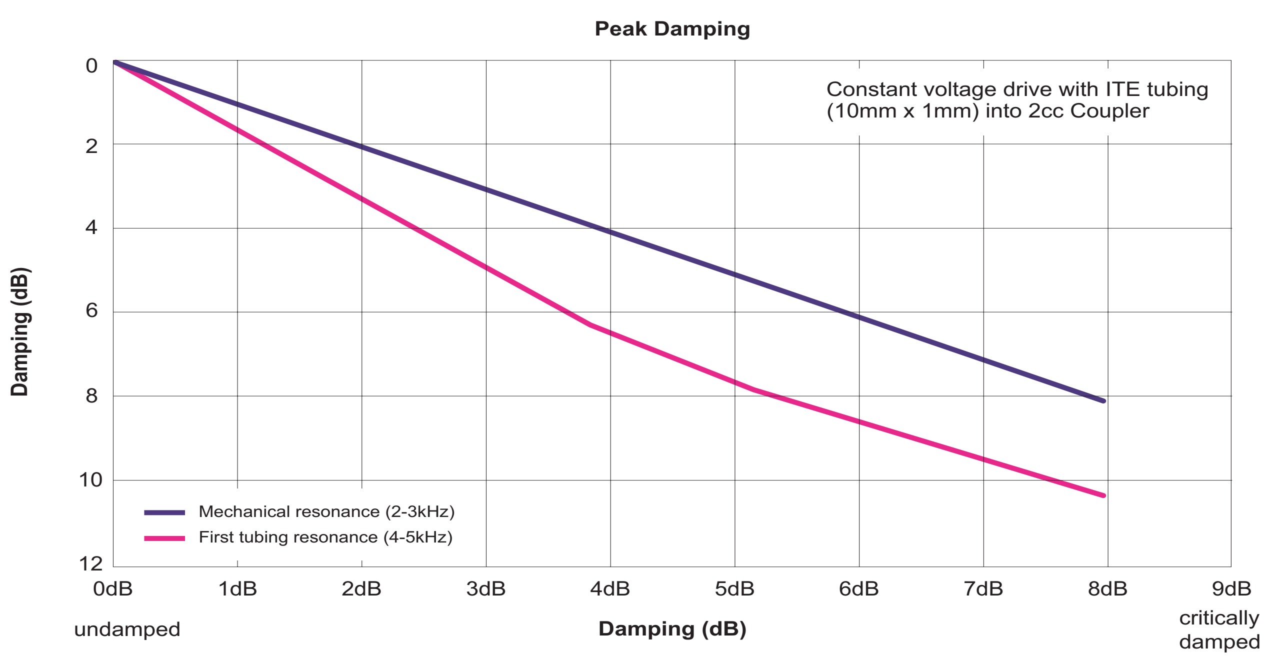

Figure 4: Damping for the first and second peaks in the frequency response of the FED receiver connected to ITE tubing and a $2cm^3$ coupler under constant voltage drive conditions.

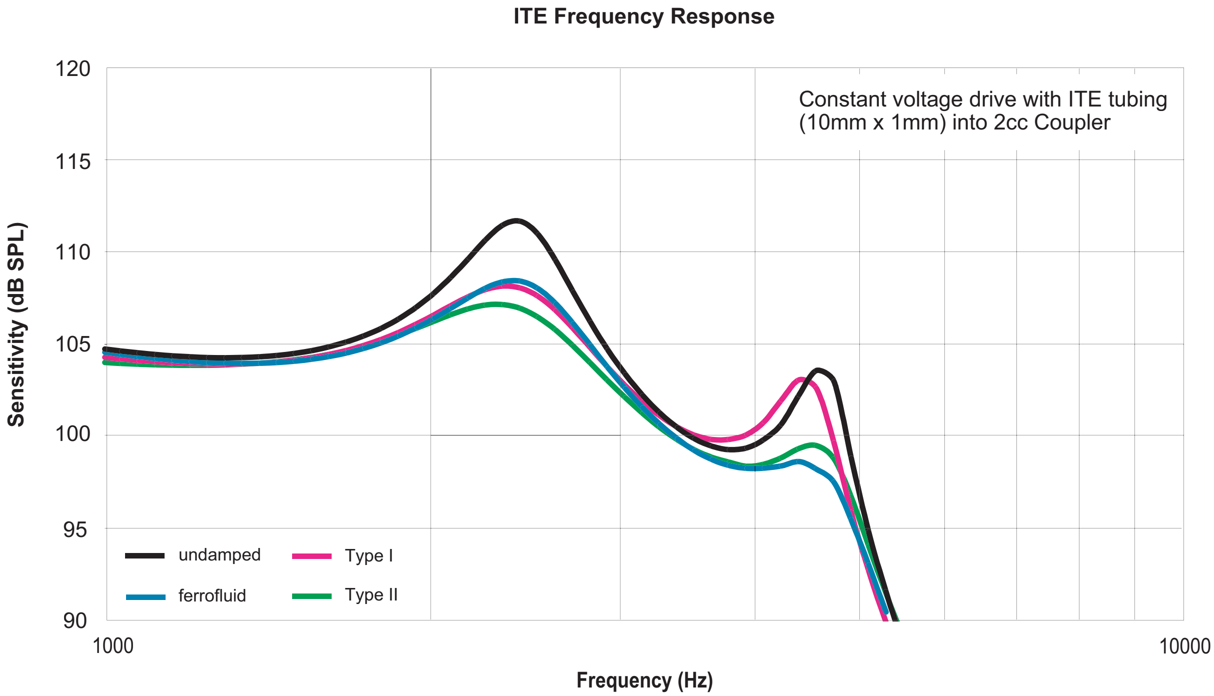

Figure 5: Frequency response of damped and undamped ED receivers connected to ITE tubing and a 2cm^3 coupler cavity under constant voltage drive conditions (magnified view).

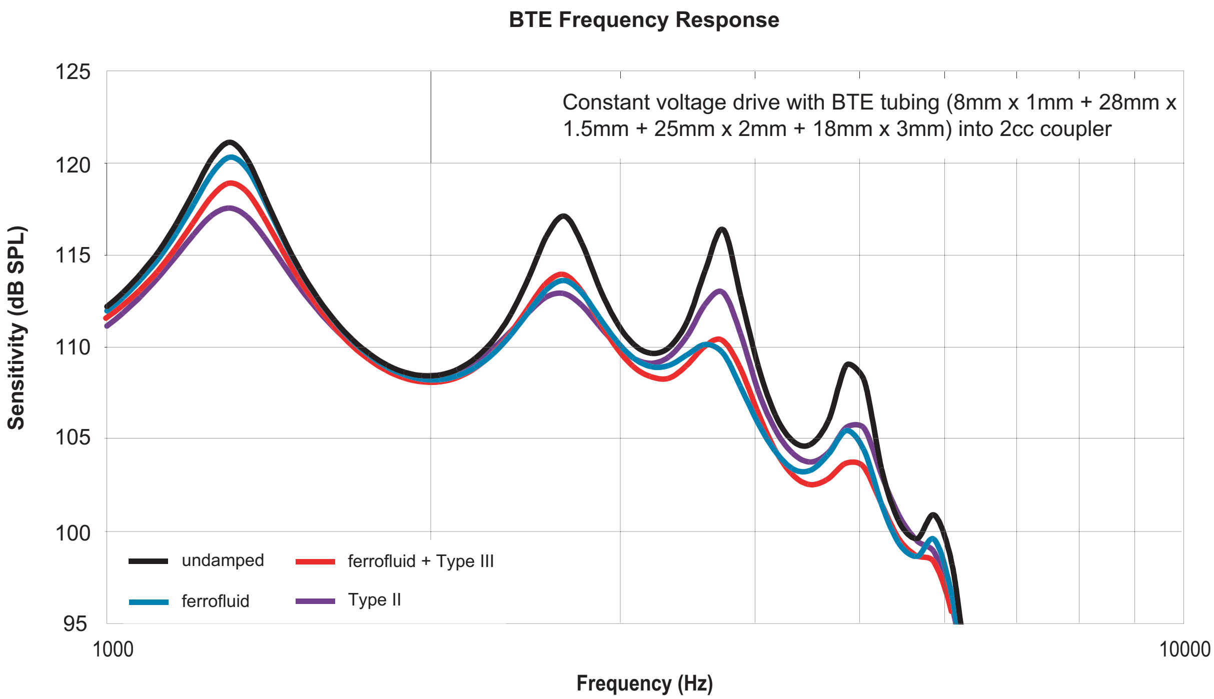

Figure 6: Frequency response of damped and undamped ED receivers connected to BTE tubing and a 2cm^3 coupler cavity under constant voltage drive conditions (magnified view).

Hot / Cold Response Data

The viscosity of the ferrofluid changes with temperature and will affect the frequency response. At higher temperatures there will be slightly less damping. At lower temperatures, the sensitivity of the receiver will be reduced. However, the receiver recovers as soon as it is warmed up again. For example, Figure 7 shows the data for an FED receiver at the limits of the operating range specifications (0°C and 63°C), room temperature (25°C), and body temperature (37°C). There is about a 1dB increase in the delta peak at body temperature. At lower temperatures, the stiffening of the fluid decreases the output of the receiver by 2dB.

Improved Shock Resistance

The ferrofluid-damped receivers have improved shock protection compared to standard receivers. Furthermore, there is no detectable fluid loss even under the most extreme conditions of shock testing. The data in Figure 8 at the top of page 6 illustrates the improved shock resistance of the fluid-damped ED receivers (FED receivers). Samples were oriented cover up and cover down and were dropped at progressively increasing heights starting at 12.7cm (5 inches) up to 196cm (77 inches). This is equivalent to decelerations of 5,000g to 20,000g.

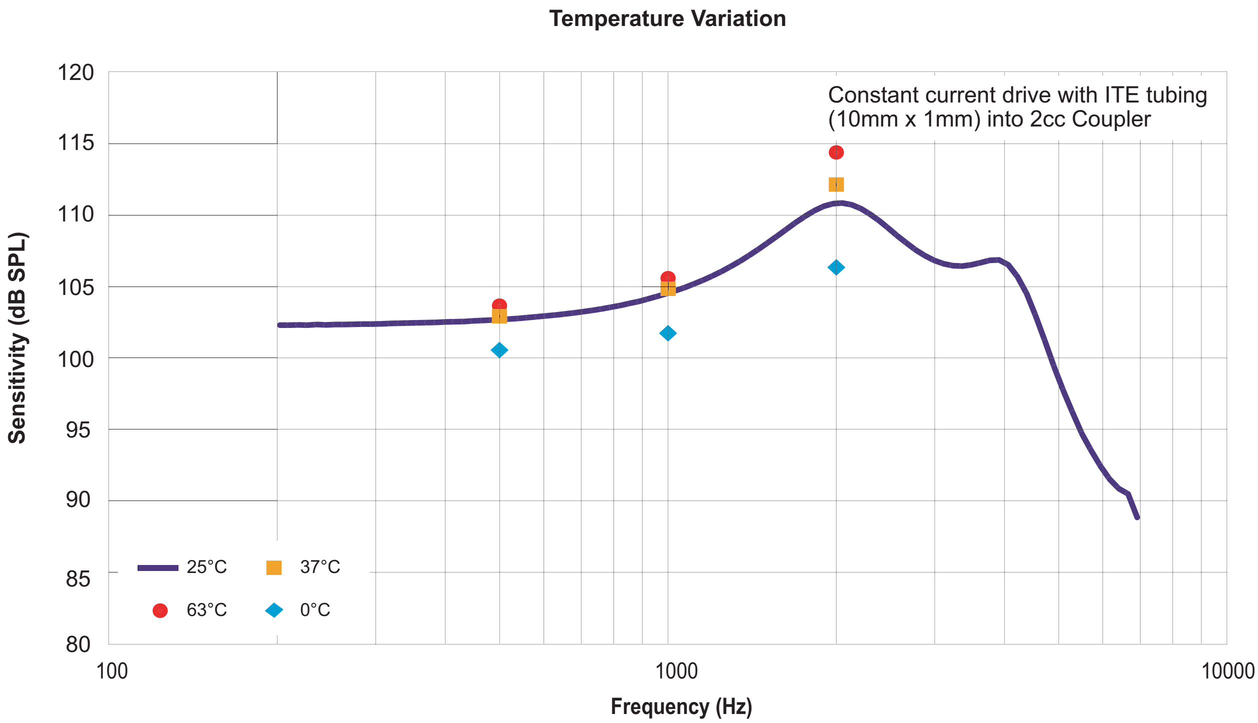

Figure 7: Frequency response of an FED receiver at temperatures: 0°C, 25°C, 37°C, and 63°C.

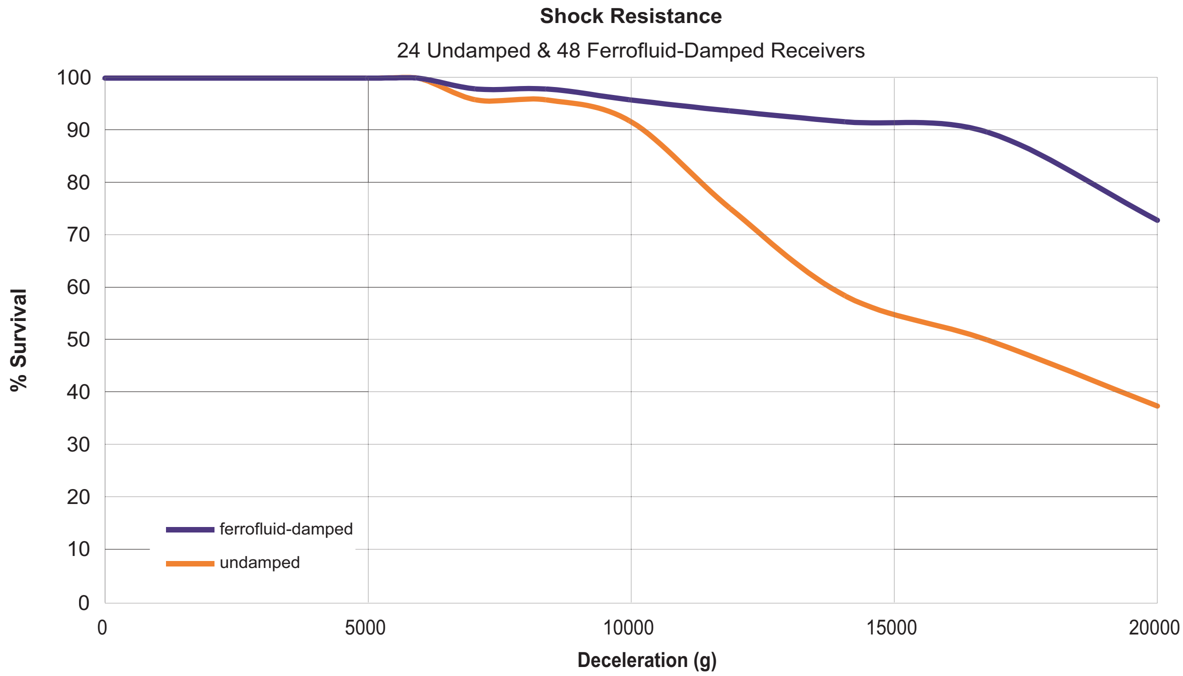

Figure 8: Percent of surviving ferrofluid-damped and undamped ED receivers for increasing drop height.

Harmonic Distortion

The total harmonic distortion will rise with increased damping (Figure 9). Figure 10 on page 7 shows the average percent total harmonic distortion (% THD) at 1/2 and 1/3 resonance versus damping under constant voltage drive conditions. Distortion is typically highest at 1/2 and 1/3 resonance where the effects of the second harmonic and third harmonic distortion are dominant. Therefore, these trends represent the “worst case”. The distortion at other frequencies will be less.

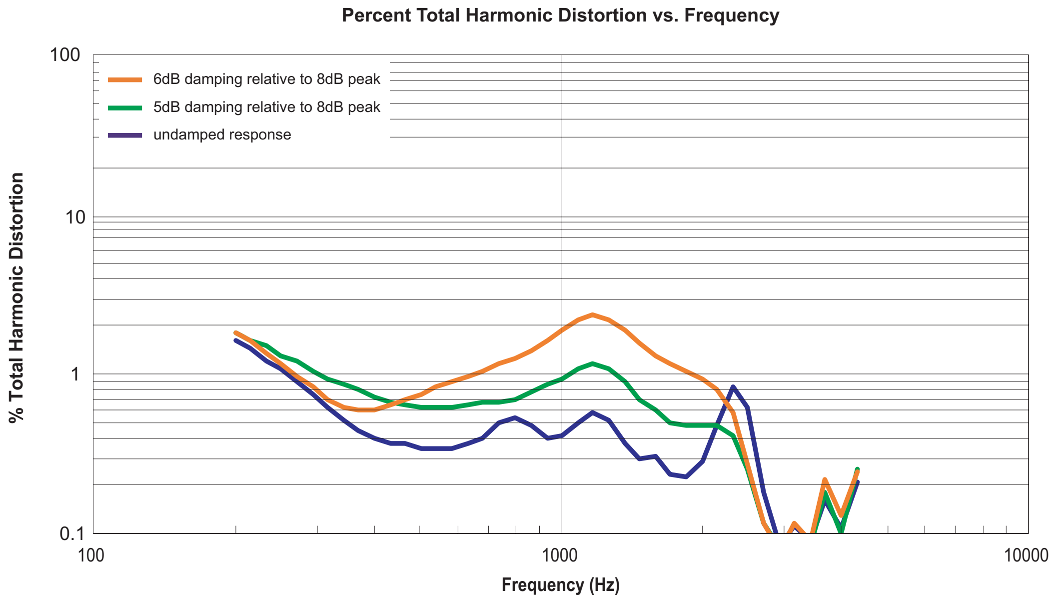

Figure 9: Percent of the total harmonic distortion versus frequency for FED receivers under constant current drive conditions.

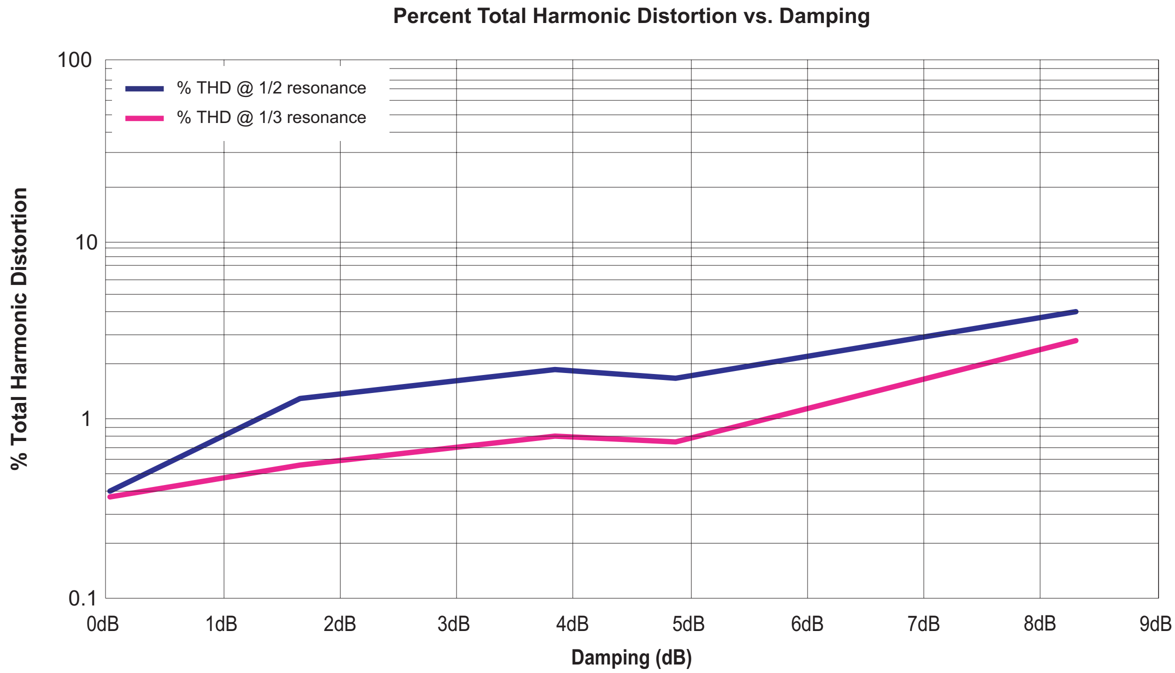

Figure 10: Percent of total harmonic distortion at 1/2 and 1/3 resonance versus damping under constant voltage drive conditions (FED receivers).

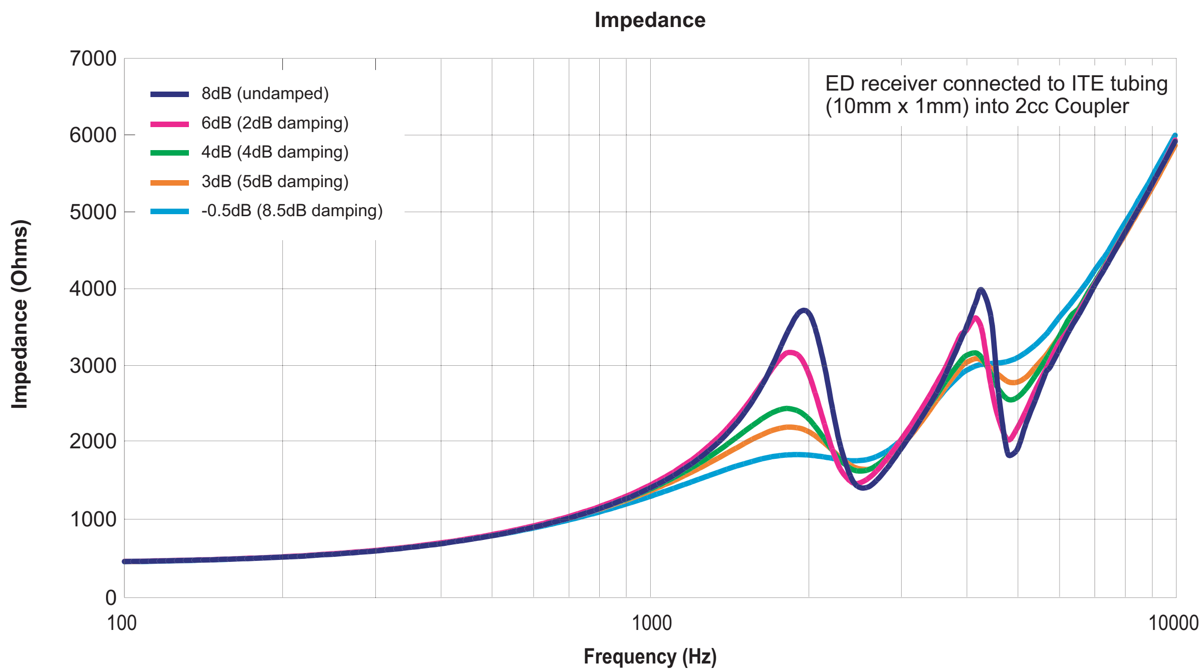

Figure 11: Impedance curves for fluid-damped and undamped ED receivers connected to ITE tubing and a 2cm^3 coupler. Labels in legend are the delta peak values under constant voltage drive conditions.

Impedance

Fluid damping also reduces the peaks in the impedance curve. Figure 11 on the previous page shows the impedance of FED receivers attached to ITE tubing and a 2cm³ coupler.

Conclusion

Ferrofluid provides a wide range of damping values and eliminates the need for a damping screen in the port tube. Fluid damping has the additional benefit of improved shock resistance. There is no fluid loss even under the extreme conditions of shock testing. The fluid viscosity will vary with temperature causing the delta peak to increase about 1dB at body temperature. There is a slight rise in the nominal harmonic distortion as damping is increased.

Knowles Electronics LLC
1151 Maplewood Drive
Itasca, Illinois 60143
Phone: (630) 250-5100
Fax: (630) 250-0575
www.knowles.com

Knowles Europe
York Road, Burgess Hill
West Sussex, RH15 9TT, England
Phone: (44) 1444 235432
Fax: (44) 1444 248724

Knowles Electronics Taiwan, Ltd.
53 Pao Hsing Road
Hsin Tien City, Taipei, Taiwan
Republic of China
Phone: (886) 2 2911 4931
Fax: (886) 2 2918 6868

Knowles Electronics Japan KK
Kyodo Bloom Building
19-1 Miyasaka 2-Chome
Setagaya-Ku, Tokyo 156-0051, Japan
Phone: (81) 3 3439 1151
Fax: (81) 3 3439 8822

Micromax Pty. Ltd.
P.O. Box 1238
Wollongong N.S.W.
2500, Australia
Phone: (61) 2 4226 6777
Fax: (61) 2 4226 6602